APPLICATION OF PALM SHELL ACTIVATED CARBON FILTER AS A MEDIUM OF INDOOR AIR CONTAMINANT ADSORBENT FOR INDOOR AIR QUALITY IMPROVEMENT

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DEDICATION

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ABSTRACT

For decades, the inclusion of activated carbon (AC) adsorption technique through filtration has gained significant interest on improvement of indoor air quality (IAQ) by reducing level of pollutant. The interest of reseachers in palm shell AC (PSAC) keep increase owing to the fact that this material has superior characteristic as compared to commercial AC. However, the investigation of PSAC performance for air filtration are still limited and no research could be found on relating the effect of burner for carbonization on PSAC properties. Therefore, the current research was focused on producing PSAC by using new fabricated burner, exploring the effect of combination of physical and chemical activation towards PSAC properties and investigating of PSAC air filter performance used in Mechanical Ventilation Air Conditioning (MVAC) system. Preliminary studies began with IAQ monitoring in different building condition. The present data revealed that at certain situation, the buildings environment was below than satisfactory level and required mitigation plan by introducing new air filtration media in MVAC system. The best quality of charcoal was obtained by Horizontal burner with less fume formation during carbonization process compare to other design. The physical properties analysis of palm shell charcoal showed the carbonization time (CT) 2 hours gained better charcoal properties and highly recommended to continue into the activation process. After the activation process, PSAC physical+chemical shows significantly higher pore development, surface area and adsorption capacity compare to the other process. The lowest density and the highest porosity up to 0.4632 g/cm^3 and 7.11% was calculated while the highest Iodine number of 1091.05 mg/g and BET surface area of 713.7 m^2/g was obtained respectively in PSAC physical+chemical. Meanwhile, microstructure and composition analysis shows that, PSAC physical+chemical fully produced honeycomb form of porosity and comprised of C, O, K and Ca contents for high adsorption capacity. The improvement of IAQ in the buildings was achieved with the application of PSAC air filter which shows low concentration of CO_2 with 302 ppm, CO with 0.4 ppm , TVOC with 0.1 ppm and PM_{10} with 0.02mg/m^3 respectively compare to the commercial filter.

ABSTRAK

Sejak beberapa dekad ini, penggunaan teknik penjerapan menggunakan karbon teraktif (AC) telah mendapat perhatian dalam menambahbaik kualiti udara dalaman (IAQ) melalui pengurangan tahap bahan cemar. Minat penyelidik terhadap karbon teraktif kelapa sawit (PSAC) semakin meningkat berdasarkan fakta ciri-ciri bahan ini yang hebat berbanding komersial AC. Walau bagaimanapun, penyiasatan terhadap prestasi penapis udara PSAC masih terhad dan tiada penyelidikan ditemui berkaitan dengan kesan pembakar melalui pengkarbonan terhadap sifat PSAC. Oleh itu, penyelidikan semasa memberi tumpuan kepada menghasilkan PSAC dengan menggunakan pembakar yang baru difabrikasi, meneroka kesan gabungan kaedah pengaktifan fizikal dan kimia terhadap sifat PSAC dan menyiasat prestasi penapis udara PSAC yang digunakan dalam Sistem Pengudaraan Mekanikal (MVAC). Kajian awal bermula dengan pemantauan IAQ dalam keadaan bangunan yang berbeza. Data semasa mendedahkan bahawa pada keadaan tertentu, persekitaran bangunan berada di bawah tahap memuaskan dan memerlukan pelan mitigasi dengan memperkenalkan media baru penapis udara bagi sistem MVAC. Kualiti arang terbaik diperolehi oleh pembakar mendatar di mana pembentukan asap berkurang semasa proses pengkarbonan berbanding dengan rekaan lain. Analisis sifat fizikal arang kelapa sawit menunjukkan sifat arang yang lebih baik diperolehi pada waktu pengkarbonan (CT) 2 jam dan disarankan untuk proses pengaktifan seterusnya. Selepas proses pengaktifan, PSAC yang diaktifkan secara fizikal + kimia menunjukkan peningkatan struktur liang, kawasan permukaan dan kapasiti penyerapan yang lebih tinggi berbanding proses pengaktifan lain. Ketumpatan terendah dan keliangan tertinggi 0.4632 g/cm^3 dan 7.11% telah dikira manakala nombor Iodin tertinggi 1091.05 mg/g dan luas permukaan BET sebanyak 713.7 m^2/g telah diperolehi dalam PSAC fizikal + kimia. Sementara itu, analisis mikrostruktur dan komposisi menunjukkan bahawa, PSAC fizikal + kimia menghasilkan sepenuhnya keliangan bentuk madu lebah dan komposisinya terdiri daripada kandungan C, O, K dan Ca untuk prestasi kapasiti penjerapan yang tinggi. Penambahbaikan IAQ di dalam bangunan telah dicapai dengan penggunaan penapis udara PSAC dimana menunjukkan kadar penumpuan yang rendah iaitu CO_2 dengan 302 ppm, CO dengan 0.4 ppm, TVOC dengan 0.1 ppm dan PM10 dengan 0.02mg/m^3 berbanding dengan penapis udara komersial.

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LIST OF SYMBOLS AND ABBREVIATION

PSAC	=	Palm Shell Activated Carbon
AC	=	Activated Carbon
CT	=	Carbonization Time
ACF	=	Activated Carbon Fibred
AHU	=	Air Handing Unit
BET	=	Brunauer- Emmett-Teller
BTX	=	Benzene, Toluene and Xylene
^{0}C	=	Degree celcius
CO	=	Carbon Monoxide
CO_2	=	Carbon Dioxide
CIF	=	Carbon-Impregnated Fiber
DOE	=	Department of Environment
FCU	=	Fan Cooling Unit
GAC	=	Granular Activated Carbon
g/l	=	Gram/liter
H_2O	=	Water
H_3PO_4	=	Phosphoric Acid
H_2	=	Hydrogen
H_2S	=	Hydrogen Sulfide
H_2SO4	=	Sulphuric Acid
IAQ	=	Indoor Air Quality
IDA	=	Indoor Air
IUPAC	=	International Union of Pure and Applied Chemistry
kHz	=	Kilo Hertz
KOH	=	Potassium Hydroxide
K_2CO_3	=	Potassium Carbonate
MVAC	=	Mechanical Ventilation and Air-Conditioning

$NaHCO_3$	=	Sodium Bicarbonate
Na_2CO_3	=	Sodium Carbonate
NAIs	=	Negative Air Ions
NaOH	=	Sodium Hydroxide
NO_x	=	Nitrogen Oxides
NTP	=	Non-Thermal Plasma
O_3	=	Ozon
ODA	=	Outdoor Air
PM	=	Particulate Matter
PCO	=	Photocatalytic oxidation
SBS	=	Sick Building Symptom
SEM	=	Scanning Electron Microscope
SO_2	=	Sulfur Dioxide
TVOC	=	Total Volatile Organic Compound
VOC	=	Volatile Organic Compound
XRD	=	X-Ray Difractrometer
$ZnCl_2$	=	Zinc Chloride
µm	=	Micrometer

CHAPTER 1

INTRODUCTION

This chapter presents the related issues pertaining to focus of the study, Indoor Air Quality (IAQ) status in Malaysia which needs to be improved, and the potential of exploring Palm Shell Activated Carbon (PSAC) as air filtration media. The limitations of previous researches in producing activated carbon as filter media are summarized and becomes the motivation for current research in improving the quality of PSAC by the activation process as mentioned in the research objectives. This study is significant as it helps to contribute in influencing the government, industry and society to improve IAQ. The novelty of this study is in terms of the methods employed in producing and activating the study process which are different from previous studies. Apart from that, Chapter 1 also describes the importance of the study in improving IAQ and the techniques generated in solving the problem.

1.1 Background of the Study

In recent years, the proliferation of industrial based company has become the source of air pollution problems in Malaysia for either indoor or outdoor environments. As confirmed by Md Razak *et al.*, 2013, the influences of human population, Gross Domestic Product (GDP) and manufacturing industry are the major contributors of pollutant gases in the country. Therefore, it is vital to create a comfortable and healthy environment for people to live and work in this modern era (Ismail *et al.*, 2010).

Demands of fresh, healthy and comfortable indoor environment are continuously present since most people spend their time predominantly indoor compared to outdoor (Abechi *et al.,* 2013). Generally, the concentration of indoor air contaminant is higher than the outdoor because it is released by human activities, building materials, furniture, carpets, paints, cleaning product and etc. (Guieysse et al., 2008). Volatile organic compound (VOC), carbon monoxide (CO), carbon dioxide (CO2), and particulate matter (PM_{10}) are defined as major contributors of indoor air contaminants. There are several VOCs in indoor air environment such as BTX (benzene, toluene xylene), trichloroethylene and dichloromethane (Das *et al.,* 2004). In long term exposure, they may pose various adverse health effects related to human respiratory system (such as asthma, throat irritation, and lung cancer), headache, poor memory, eyes, nose and also skin irritation (Jo & Chun, 2014 and Eugenija *et al.* 2009). Therefore, the maintenance of the indoor air quality is needed in order to provide sustainable and healthy environment (Yoo *et al.,* 2015). The increasing concern towards IAQ have generated suitable techniques on mitigating the indoor air contaminant which affect people's health and working performance (Yu *et al.*, 2014 and Yu *et al.,* 2009).

There are a number of methods utilized for controlling indoor air pollutant such as ventilation and air cleaning method (Kabir & Kim, 2012). Mechanical Ventilation and Air-Conditioning (MVAC) system has been proven effective in reducing indoor particulate level. However, the technique does not promise to diminish contaminant gases; in fact, it requires more energy consumption (Haghighat *et al.,* 2008). Adsorption in bulk separation or purification process has an innovative treatment process in environment application and is effective at low concentration level which is part per million (ppm). Large adsorption capacity is achieved by employing large surface area of the filter material and their performance in both equilibrium and kinetics. Air purification through Activated Carbon (AC) adsorption technique is the most common air cleaning method, especially for VOC and other polluted gases (Das et *al.*, 2004 and Khan & Ghoshal, 2000). This type of adsorption technique can improve indoor air quality and reduce cancer risk and non-cancer risk health problems. Silica gel, zeolite alumina and AC amongst several adsorption media which are commercially available or already existed in the market. However, AC is one of the cheapest and popular materials which can be used hundred or thousand times in a broad spectrum of applications for a growing range of environmental, industrial, health, and safety applications (Cukierman, 2013 and Adedayo *et al.,* 2012). There are many advantages of AC such as high carbon content, low ash content, high density, high absorption capacity, dissolving organic ability, chlorine removal capability and can be used as a specific application (Adedayo *et al.*, 2012; Onundi *et al.*, 2010; Wan Nik *et al.*, 2006 and Hasan *et al.*, 2013). The other superiority of AC criteria include large surface area, numerous pores network as transportation media of molecules to the interior and more stable performance in dynamic condition (Abechi *et al.*, 2013).

The development of AC commonly involves high degree temperature from the carbonization until activation process. Recently, AC was burned at various temperatures using a commercial burner which was unidentified reference to burner design (Sidheswaran *et al.*, 2012; Koo *et al.*, 2015 and Anirudhan & Sreekumari, 2011). In design perception, burner with precise control is needed to ensure the hot gas is free of oxygen; otherwise, some of the raw AC is burned instead of being merely carbonized. The burner does not frequently release heat and air flows which cause overheating of the burner and leads to high volume of ash content and decreasing adsorption properties of AC. During combustion of AC's raw material process, SO_2, NOx and particulate matter are released contributing to the environmental problems. In term of air filter design, production of large amount of granular AC is needed in order to be effective in contaminant adsorption. However, most researchers use commercially available furnace which is suitable for little amount per unit of space occupied for AC's carbonization.

Currently, Malaysia is the second world largest exporter of palm oil. Therefore, large amount of waste from oil palm parts including palm fiber, palm shell and empty fruit bunch is yielded since oil is only extracted from the fruits. Oil palm waste can be manipulated to many forms such as organic fertilizer, animal feed, alternative energy (fuel) and activated carbon (Martinez *et al.*, 2003 and Cobb *et al.*, 2012). Abdullah & Wahid, (2010) suggested an AC that has several base properties such as bulk density (0.4-0.47), moisture content (3%), ball-pan hardness (90-95%), ash content (5-7%), iodine number (950-1100 mg/g) and pH value (10). Recently, many studies were conducted on the pore development of palm shell activated carbon (Koo *et al.*, 2015;Nasri *et al.*, 2014; Akpa & Nmegbu, 2014; Hussaro, 2014; Chew *et al.*, 2013; Abechi *et al.*, 2013; Ello *et al.*, 2013 and Arami-Niya *et al.*, 2011). The pore development on activated carbon can be increased by physical and chemical treatments.

According to some literature, constant temperature and relative humidity in real buildings of various conditions vary significantly between months, seasons and years; hence, influences the IAQ (Reed *et al.*, 2008 and Gallego *et al.*, 2013). Meanwhile, filters available in the market have not been scientifically evaluated; therefore, real VOC contaminants in real life buildings are not yet recorded (Gallego *et al.*, 2013). Few other researchers started to investigate activated carbon as an air filter (Muala *et al.*, 2014; Jo & Chun, 2014; Son *et al.*, 2011; Haghighat *et al.*, 2008 and Chang *et al.*, 2006). However, they utilized conventional activated carbon commercially available in the market; hence, facing a common problem which was slow inter-particular diffusion.

1.2 Problem Statement

The commonly used mechanical ventilation in indoor environment has significant effect on removing particles but not practically suitable on removal gaseous contaminant (Haghighat *et al.*, 2008). Therefore, air cleaning technique through activated carbon adsorption is the most suitable in diminishing harmful pollutant (Khan & Ghoshal, 2000). Recently, sustainable production of AC is needed throughout the world for commercial AC consumption and due to its wide applications (Roskill, 2014). Hence, low cost precursor such as palm shell is preferred to overcome the problem of AC's feedstock.

In earlier stages of AC production, high temperature is involved during the carbonization process (Abechi *et al.*, 2013). The design of burner is usually made in simple which leads to high volume of ash content in charcoal production; hence, contributing to damaging environment and inefficient performance (Syred *et. al*, 2006). Otherwise, previous research shows that, the carbon yield for various types of charcoal burner was recorded at 49.9% in average which means half of the total carbon inside raw material emitted to the air (Glaser *et. al.*, 2002). Therefore, a precise design of burner with fume handling system is needed during carbonization process to maintain healthy environment and increase the carbon fixation potential (Eurocarb, 2010).

In order to improve the properties of PSAC, some parameters need to be considered during the activation process for air filtration applications (Koo *et al.*, 2015; Nasri *et al.*, 2014; Hussaro, 2014 and Ello *et al.*, 2013). Most of PSAC is produced by either physical or chemical activation process and this has been investigated by many researchers (Sumathi *et al.*, 2010; Akbar *et al.*, 2013; Chew *et al.*, 2013; Ello *et al.*, 2013; Nasri et al., 2014; Akpa & Nmegbu, 2014 and Hussaro, 2014). Thus, the investigation regarding the combination of physical and chemical activation methods in PSAC production is quite a challenge to be explored.

The exploration of AC performance for various air filtration applications such as particulate matter, VOC and other pollutant gases filters in different environments continues to rise (Muala *et al.*, 2014; Jo & Chun, 2014; Son *et al.*, 2011; Haghighat *et al.*, 2008 and Chang *et al.*, 2006). However, it is limits to commercial AC and not for PSAC (Fisk *et al.*, 2013). Therefore, the investigation of PSAC filter performance in different indoor environments need to be fully explore particularly its effectiveness towards IAQ.

1.3 Research Objectives

The objectives of the research work reported in this thesis are as follow:

i. To investigate IAQ status in commercial building and industry for the requirements of PSAC air filter in improving IAQ.
ii. To develop a green technology burner for charcoal production and to produce PSAC using physical, chemical and combination of physical and chemical methods in granular form in developing the air filter.
iii. To analyse physical and chemical properties as well as the characteristics of PSAC and raw palm shell charcoal.
iv. To analyze IAQ improvement in commercial building using granular PSAC air filter.

1.4 Research Scope

IAQ is very important for human comfort in performing their daily activities. Thus, the study focused on burner development and PSAC production.

i. This study focused on the development of PSAC filtration system located inside the air-conditioning system. Data collection was taken before and after the implementation of palm shell AC filter.

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